Microstructure and process for the production of microstructures

The invention relates to microstructures and a process for the production of microstructures which are formed by the superimposition of a relief structure with at least one second relief structure.

Light-diffracting microstructures have a plurality of recesses which are generally in the form of parallel grooves and which for example form an optical grating with a microscopically fine relief structure. Light which is incident on the microstructures is diffracted or scattered in a manner which is predetermined by the microstructure. Mosaics consisting of the microstructures are shaped for example in plastic material or metal and serve as authenticity features for valuable articles. Those authenticity features exhibit a striking optical behaviour and are difficult to imitate.

Some processes are known for the production of microstructures of that kind. Thus mechanical apparatuses produce the microstructures by scratching many parallel grooves in a substrate surface. The shape of the scratching tool determines the profile of the relief structure. The operation of scratching the relief structure becomes progressively more difficult and consequently expensive, with an increasing number of lines per millimeter. Holographic processes are less expensive, wherein two coherent light beams from a laser light source are caused to interfere on a photosensitive layer of photoresist. The interference image with its light and dark fringes expose the photoresist in accordance with the local level of light intensity. After development the surface of the photoresist has a relief structure of a symmetrical profile. In a further process an electron beam draws the relief structure groove by groove in the layer of photoresist, in which case the grooves can also form curved lines. The microstructure master shapes produced in accordance with those processes can be replicated galvanically and with the copies produce metallic stamping punches with which the shape of the microstructures can be produced in metal or plastic material. With those processes however the apparatus expenditure for the production of microstructures is extremely high.

It is also known from EP-A 0 105 099 for new microstructures to be synthesised in the form of a mosaic, in which case one out of a set of different relief structures, oriented in a predetermined manner in the azimuth, is mechanically shaped in each surface element of the mosaic.

The object of the invention is to propose a microstructure, for example for a replication master, which is relatively easy to produce with a high degree of accuracy and which is complicated and consequently difficult to imitate, and an inexpensive process for the production of a microstructure whose relief structure is produced by a superimposition of at least two relief structures.

According to the invention the specified object is attained by the features recited in claims 1 and 9 and is based on the idea of combining a stamping or other mechanical shaping process with a photostructuring in order to produce microstructures which are inexpensive but nonetheless complicated. Advantageous configurations of the invention are set forth in the further claims.

An embodiment of the invention is described in greater detail hereinafter and illustrated in the drawing in which:

Figure 1 shows a substrate with a layer of photoresist,

Figure 2 shows the stamped surface of the layer of photoresist,

Figure 3 shows a matt structure,

Figure 4 shows the operation of exposing the photoresist,

Figure 5 shows a profile of a microrelief, and

Figure 6 shows a stamping punch with a relief die.

Referring to Figure 1, shown therein in cross-section is a first step for the production of optically diffractive structures. A layer 2 of photoresist is applied to a flat substrate 1 of metal, glass, ceramic or plastic material. The thickness d of the layer 2 is in the region of between 0.1 μm and 100 μm and depends on the depth of the diffractive structures to be produced. Photosensitive photoresist materials are known, for example from Shipley, the product Microposit S 1813. The photoresist material is applied to the substrate 1 in liquid form and solidified under the effect of heat. In a preferred variant a relief die 4 mounted on a stamping punch 3 is lowered

into the flat free surface of the layer 2 and impressed into the free surface of the layer 2 so that the shape of the relief die 4 is produced in the free surface of the layer 2.

As shown in Figure 2, after the stamping punch 3 (Figure 1) is lifted off, the layer 2, in the region of the stamping punch, has a relief structure 5 which is a negative of the relief die 4 (Figure 1). The substrate 1 is not to deform or flex during the stamping operation so that the relief die 4 transfers the relief structure 5 on to the layer 2 with the utmost fidelity in respect of shape.

Without restricting the meaning of the term 'relief structure' 5, Figure 1 of the drawing shows the profile of the relief die 4, the shape of which is to be formed in the substrate, by way of example with a symmetrical sawtooth profile of a periodic grating. In particular also one of the other known profiles such as for example asymmetrical sawtooth profiles, rectangular profiles, sinusoidal or sine-like profiles, a regular arrangement of pyramids and so forth which form a periodic linear grating or cross grating are suitable for the relief structure 5. The spatial frequency of the relief structure 5 can be selected from the wide range of between 1 line/mm to some 1000 lines/mm. The structural depth T of the relief structure 5 of a periodic grating is usually in the region of between 0.1 μm and 100 μm, in which respect, for technical reasons, relief structures 5 of a great structural depth T (Figure 1) typically have a low value in respect of the spatial frequency.

In another variant of the process an isotropic or anisotropic matt structure which forms the relief structure is shaped into the surface of the layer 2. The matt structures include microscopically fine relief structural elements which determine the scatter capability and which can only be described with statistical parameters such as for example mean roughness value R_a, correlation length I_c and so forth, the values in respect of the mean roughness value R_a being in the region of between 20 nm and 2500 nm, with preferred values of between 50 nm and 500 nm. At least in one direction the correlation length I_c is of values in the region of between 200 nm and 50,000 nm, preferably between 1000 nm and 10,000 nm. The

microscopically fine relief structural elements of the isotropic matt structure do not have an azimuthal preferred direction, for which reason the scattered light of an intensity which is greater than a limit value which is predetermined for example by visual perceptibility, is distributed uniformly in a spatial angle predetermined by the scatter capability of the matt structure, in all azimuthal directions. Strongly scattering matt structures distribute the scattered light into a larger spatial angle than a weakly scattering matt structure.

If in contrast the microscopically fine relief structural elements have a preferred direction in the azimuth, the matt structure scatters incident light anisotropically. The spatial angle which is predetermined by the scatter capability of the matt structure is of a cross-sectional shape in the form of an ellipse whose long major axis is perpendicular to the preferred direction of the relief structural elements. In contrast to the diffractive structures the matt structures scatter the incident light practically independently of the wavelength thereof, that is to say the color of the scattered light substantially corresponds to that of the light which is incident on the matt structures.

Figure 3 shows a cross-section by way of example through one of the matt structures, the shape of which is produced in the layer 2 as a relief structure 5. Instead of the structural depth T (Figure 1) of the gratings the profile of the matt structure has the mean roughness value R_a. The fine relief structural elements of the matt structure exhibit greatest differences in height H up to about 10 times the mean roughness value R_a. The greatest differences in height H of the matt structure therefore correspond to the structural depth T for the periodic gratings. The values of the differences in height H of the matt structures are in the above-indicated range of the structural depth T. The details set out hereinafter in respect of the range of the structural depth T therefore apply both to relief structures 5 with periodic gratings and also relief structures 5 with matt structures.

Reference is now made to Figure 4 to describe a holographic process which, by means of photostructuring of the relief structure 5, additively superimposes a diffraction grating (not shown in Figure 4). A coherent light

beam 6 of a wavelength of for example 400 nm is produced in a laser light source 7. The light beam 6 impinges on a beam splitter 8. The beam splitter 8 deflects a part of the light beam 6 in the direction of the relief structure 5, as a partial beam 9. The rest of the light which passes undeflected through the beam splitter 8 forms a reference beam 10. A deflection mirror 11 also directs the reference beam 10 on to the relief structure 5. The partial beam 9 and the reference beam 10 are fanned out in such a way that each of the beams 9, 10 would individually illuminate the entire relief structure 5 with parallel light beams. The direction of the partial beam 9 differs from the direction of the reference beam 10 so that the partial beam 9 and the reference beam 10 intersect at a predetermined intersection angle in the region of the structured surface. Because of the coherence of the light waves and the wavelength difference of the two beams 9, 10, the partial beam 9 and the reference beam 10 interfere with each other in such a way that an interference pattern is produced on the relief structure 5. The interference pattern includes parallel fringes of a high level of light intensity which are separated by fringes of a low level of light intensity, wherein the fringes of the interference pattern perpendicularly intersect the track of a plane defined by the partial beam 9 and the reference beam 10, on the relief structure 5. The number of fringes per millimeter is determined by the wavelength of the light forming the beams 6, 9, 10 and by the intersection angle at which the partial beam 9 and the reference beam 10 intersect.

By virtue of rotation of the substrate 1 about a normal 15 to the plane of the substrate 1, the substrate 1 and therewith the relief structure 5 are oriented in respect of azimuth with the interference pattern prior to the exposure operation and a predetermined azimuth value is set.

The material of the above-mentioned photoresist is altered by exposure with the interference pattern only in the fringes involving the high level of light intensity, in such a way that, after exposure, the material of the photoresist is dissolved under the effect of the developer, for example Shipley Mikroposit 351. In that case, recesses are produced in the surface of the photoresist, in the form of parallel grooves of a diffraction grating

whose grating period is equal to the spacing of the fringes in the interference pattern. The grating period is adjustable insofar as the intersection angle at which the partial beam 9 and the reference beam 10 intersect is changed. The wavelength of the light beam 6 is predetermined by the laser light source and must be suitable for exposure of the photoresist of the layer 2.

The profile of the grooves and the geometrical profile depth t thereof are determined by the exposure time, the development time and the light intensity. The depth of the grooves reaches a predetermined value of normally 250 nm. The profile is symmetrical and extends from a simple sine profile to a rectangular profile. The position of the grooves is determined by the fringes of the interference pattern. Therefore the grating lines of the relief structure 5 and the grooves of the diffraction structure differ in respect of azimuth by the set predetermined azimuth value.

Figure 5 shows the surface of the layer 2 after photostructuring of the relief structure 5 (Figure 4). A microstructure 12 has been produced in the surface of the layer 2, which is produced by additive superimposition of the relief structure 5 with the holographically produced diffraction structure, wherein, in the example, the grating lines of the relief structure 5 and the grooves 13 of the diffraction structure involve the same azimuthal orientation. The original relief structure 5 is indicated in Figure 5 by means of a broken line 14. The photoresist which was originally present between the broken line 14 and the microstructure 12 has been removed in the development operation.

After drying of the photoresist the shape of the microstructure 12 is galvanically produced in nickel in known manner, thus producing a master of the microstructure 12. The reflecting master is subjected to a check to ascertain whether the optical properties of the master correspond to the expected properties. That master is then used to produce copies with which portions from the master are combined in plastic material or metal with other diffraction structures, mirror surfaces and so forth, to afford a mosaic-like pattern for an optical security element.

That production process has the advantage that it is substantially ensured (and better than when using other processes) that a genuine addition of the structures to be combined, the relief structure 5 and the diffraction structure, is achieved for the microstructure 12, with the geometries of the relief structure 5 and the diffraction structure being substantially retained.

In this respect it is also possible to combine structures which differ greatly in respect of their dimension. For example the relief structure 5 can be of a structural depth T of more than 2 μm and can be one of the matt structures or one of the gratings or indeed microprisms of a retroreflector. The relief structure 5 is superimposed with the diffraction structure with a low value in respect of the grating period.

In a first process for the production of the microstructure 12, one of the above-described periodic gratings is shaped into the layer 2 in the form of a relief structure 5 which is photostructured with the diffraction structure. In a specific embodiment the spatial frequency of the diffraction structure is at least five times higher than the spatial frequency of the relief structure 5.

In a second process for production of the microstructure 12, one of the above-described matt structures is shaped into the layer 2 which is photostructured with the diffraction structure. The grating period of the diffraction structure is at most 500 nm so that light is reflected only into the zero diffraction order. The advantage of that microstructure 12 is that it combines the scatter capability of the matt structure with the properties of the diffraction grating, such as for example wavelength-selective reflection capability, polarisation capability and so forth.

The processes for production of the microstructure 12 can be enlarged in a first manner insofar as, after the previous photostructuring has been effected, the intersection angle at which the partial beam 9 (Figure 4) and the reference beam 10 (Figure 4) intersect is altered, and a further photostructuring operation is effected with an interference pattern whose fringe pattern is altered in respect of the number of fringes per millimeter in comparison with the previous photostructuring. That

expansion of the process with a different setting in respect of the spatial frequency of the fringe pattern is effected once or repeated a plurality of times with different spatial frequency values until the predetermined microstructure 12 is reached.

The processes for production of the microstructure 12 can be enlarged in a second manner insofar as, after the previous photostructuring operation has been effected, a further photostructuring operation is effected with a different azimuthal orientation of the substrate 1 in relation to the interference pattern formed by the partial beam 9 (Figure 4) and the reference beam 10 (Figure 4). That expansion of the above-described photostructuring operation with a different setting in respect of the azimuthal orientation is effected once or repeated a plurality of times with different azimuthal orientations until the predetermined microstructure 12 is reached.

The processes for production of the microstructure 12 can be varied in a third manner insofar as, after the previous photostructuring operation has been effected, both the spatial frequency of the fringe pattern and also the azimuthal orientation are altered and then a further photostructuring operation is carried out. That expansion of the above-described photostructuring operation with a different setting in respect of the spatial frequency of the fringe pattern and the azimuthal orientation is effected once or repeated a plurality of times with different setting values until the predetermined microstructure 12 is reached.

In the process described as the preferred process, step a) involves using a stamping process for producing the shape of the relief structure 5. It is however also possible for the process to be altered in step a) in such a fashion that the relief structure 5 is already shaped when casting the layer 2. In that case, the liquid photoresist is poured into a casting mold comprising the substrate 1 and the relief die 4 (Figure 1) disposed in opposite relationship to the substrate 1. The relief die 4 is removed after solidification of the photoresist under the effect of heat. The free surface of the layer 2 has the relief structure 5 as the negative of the relief die 4.

In a further variant of the process, in step a), instead of stamping or casting, the relief structure 5 can be mechanically cut into the layer 2 directly with a cutting stylus.

A variant of the process as shown in Figure 6 uses as the relief die 4 a structure which includes at least one paraboloid surface 16 and/or cone tip 17. The paraboloid surfaces 16 and/or the cone tips 17 are also combined with the above-described periodic grating. The shape of the relief die 4 is produced in the layer 2 on the substrate 1. The photostructuring operation is then performed.

A further variant of the process for producing the microstructure 12, instead of using the grating or the matt structure as a relief die 4, uses an already existing combination structure with superimposed structures, which in the above-described process steps is firstly shaped into the surface of the layer 2 of photoresist to produce the relief structure 5, and is then further subjected to photostructuring.

It is known that, besides the above-described, positively acting photoresist, it is also possible to use a negatively acting photoresist (Futurrex NR7 – 1000PY) which is highly suitable for that process.